5p

N63-12593

NASA TN D-1649

code-1

NASA TN D-1649

TECHNICAL NOTE
D-1649

A FLIGHT EVALUATION OF LUNAR LANDING

TRAJECTORIES USING A JET

VTOL TEST VEHICLE

By L. Stewart Rolls and Fred J. Drinkwater III

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON February 1963

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-1649

A FLIGHT EVALUATION OF LUNAR LANDING TRAJECTORIES USING A JET VTOL TEST VEHICLE

By L. Stewart Rolls and Fred J. Drinkwater III

SUMMARY

A preliminary survey was made in a jet propelled VTOL aircraft of the problems associated with performing lunar landing trajectories. The similarity of the lift and reaction-type controls in a jet-supported VTOL aircraft and a lunar landing craft made the X-14A useful for this study.

Four different flight paths starting at 1000 feet altitude and one mile from touchdown and requiring one to two minutes were investigated. The tests indicated that the pilot could complete the landing mission from hover without difficulty and that there were only minor differences between the various flight paths tested. Removing the rotary damping had a negligible effect on the ability of the pilot to perform the landing. These tests showed that when the pilot could see both the horizon and the target he could make a quick and precise visual landing. The pilot used step-type thrust inputs during these trajectory studies.

INTRODUCTION

The approach and landing from a low-altitude hovering condition above the lunar surface is one phase of the Apollo mission. Currently, several simulator investigations are being conducted to determine trajectory characteristics and pilot control requirements for this maneuver. Elaborate moving-cab and free-flight simulators are being considered to advance the state of the art beyond the fixed-base simulation stage. To establish an immediate insight into the nature of the flight problems to be encountered, consideration was given to the use of a currently operating vertical take-off and landing (VTOL) aircraft. There is a great similarity in the flight-control problem between a jet supported reaction-jet controlled VTOL vehicle and a lunar landing craft since lift and control are generated in the same fashion. Thus it is logical to use this type of vehicle to assist in locating possible problem areas associated with the final phases of a lunar landing mission. The X-14A is a vectored thrust VTOL test vehicle equipped with the necessary controls to vary the control power and damping characteristics, and having the important capability of operating with negligible

aerodynamic lift and zero rotary damping. Hence, it was considered a useful vehicle for simulating in free flight the approach to the lunar surface and the landing.

This report presents the results of a preliminary flight study in which the X-14A VTOL aircraft was used to duplicate various possible trajectories of a vehicle making a lunar landing from a hovering condition. The results illustrate the effects of trajectory and the effect of damping on the pilot's ability to follow a trajectory.

DESCRIPTION OF TEST VEHICLE

The results presented in this report were obtained from a flight investigation using the X-14A variable-stability and control VTOL test vehicle. The X-14A, shown in figure 1, is a fixed-wing, jet-propelled, vectored-thrust aircraft. The exhaust from the jet engines passes through cascade-type diverters which enable the pilot to select vertical or horizontal thrust. For these tests thrust was kept parallel to the vehicle's vertical axis at all times. During hover and low-speed flight, control of the airplane attitude was maintained by the use of reaction jets at the wing tips and the tail with the air for these controls being bled from the compressor of the turbojet engines. A detailed description of the X-14A and a discussion of its use in a visual hovering task is presented in reference 1. The pilot's control system consisted of a conventional center stick and rudder pedals and the control moments were linearly proportional to control displacements. This type of control provides the pilot with a finer control of the aircraft motions than would be available with an on-off type of control. The vehicle had a maximum thrust-to-weight ratio of 1.2. For the majority of these tests values of control power and damping were set to provide an acceptable control system for hovering this vehicle as determined in reference 1. These control characteristics are presented in the following table:

Axis	Control power (max), radians/sec^2	Rotary damping, 1/sec
Pitch	0.65	0.46
Roll	2.05	1.40
Yaw	0.70	0.52

TESTS

Following the braking phase of the lunar letdown, the Apollo vehicle is assumed to be at 1000 feet altitude and one mile from a preselected landing site at zero velocity. These are the initial conditions for this study. The path of

the test vehicle was selected to be in a vertical plane through the touchdown point and the starting point with no lateral offset maneuvers required. A photograph of the pilot's view of the selected touchdown point, as seen from the starting point for each trajectory, is shown in figure 2. The final portion of one of these profiles was photographed with a Fairchild Data Analyzer Camera and is shown in figure 3. During each test run the pilot maneuvered from zero velocity at the initial point to the selected touchdown point in the shortest practical time on a prescribed trajectory. Only the general shape of these profiles was outlined to the pilot before the flight and no attempt was made to maintain a precise time-distance relationship during the maneuver. Aircraft and ground-mounted instrumentation were used to determine the pilot's work load, the vehicle motion, and the flight path. The five flight profiles studied are shown in figure 4. Profiles 1 and 5 were the same except that for profile 5 the aircraft rotary damping about all three axes was cancelled by the variable stability system in the test vehicle. In all these flight maneuvers the task being performed was negligibly affected by the vehicle's wing. The flight velocities and angle of attack of the wing were sufficiently low to minimize any motion induced by wing stalling or lifting.

While performing these maneuvers, the pilot relied upon outside visual and motion cues. These tests were conducted in smooth, calm air, with winds less than 5 knots, and with good visibility conditions.

RESULTS AND DISCUSSION

Comparison on Basis of Fuel Consumption

A prime factor in evaluating various lunar landing trajectories is the amount of fuel necessary to complete the maneuver. On a lunar craft, it is necessary to consider fuel used for control, via the reaction jets, as well as for the main lift-producing engines. It was felt that for comparison purposes the time required to complete the letdown and landing would be an approximate measure of the amount of fuel used in the main propulsion engines, and that the standard deviation of the control motions would indicate the amount of control fuel required. Comparisons are based on these quantities and no attempt has been made to establish real fuel requirements.

The various trajectories are compared on figure 5 on the basis of time required to complete the trajectory from the initial point to the touchdown. Also shown is the factor indicating the magnitude of control inputs required, both by the pilot and by the rotary damping system. This figure indicates that trajectory 4, requiring the least time, would require the minimum amount of propulsion fuel. This trajectory is performed with a large acceleration taking place at the start; and the higher velocity is maintained throughout the flight path to reduce the time required to traverse the distance. Trajectory 3 required the longest time because of the pilot's difficulty in monitoring vertical motion at the high altitudes and his reluctance to approach the ground rapidly with limited visibility downward. From the limited amount of data obtained, it

appears that variations of the order of 5 seconds would occur for the same flight profile flown on successive days, because of the difficulty of starting from exactly the same point in space each time.

The data presented on figure 5 indicate that trajectory 4 also required the larger control inputs. This is the result of the larger attitude changes required to execute the maneuver. Thus, while this flight path requires the least amount of fuel for the lift engines, it requires the most fuel for control. It was not possible in this study to derive a total fuel consumption because of the lack of configuration details; however, it is felt that the amount of fuel for control will be considerably less than that consumed by the main engine.

Comparison on Basis of Control Activity

Attitude control.- The standard deviation of the movement of each control in terms of the percent available in one direction, during each prescribed trajectory, is presented on figure 6. These data indicate that in all cases the motion of the controls was small but, as expected, that of the longitudinal axis was greatest because changing the pitch attitude was the primary means of controlling the trajectories. This is shown particularly by the increased standard deviation in trajectories 2 and 4, where larger changes in flight path were made. The slight increase in pilot's effort for the case with zero rotary damping (trajectory 5) is also shown.

The small amount of control used during these maneuvers indicates that the control characteristic requirements for a hovering VTOL vehicle as indicated in reference 1 are extremely conservative for this task. This is influenced by the different environment in which the two types of vehicles will be required to operate. The requirements for a hovering VTOL vehicle are influenced strongly by the requirement of maintaining a reserve of control power to enable the pilot to have control capability in the event the vehicle experiences unexpected gusts. For the lunar vehicle this will not be the case; thus, the same degree of control margin is not required. To be realistic in simulating lunar conditions these tests were flown in smooth, calm air; thus the control inputs are felt to be reasonably representative of a lunar operation.

The standard deviation of the aircraft's angular velocities is presented on figure 7 as an indication of the vehicle's steadiness. These results indicate a high degree of steadiness since only $3/4^{\circ}$ to $1\text{-}1/2^{\circ}$ per second of angular velocity was required. These data also indicate a slight increase in angular rates while the vehicle was operating with zero rate damping. Since the rotary velocities developed about any axis were small, the control inputs to the airframe to supply rate damping were also small.

Vertical velocity control.- The control of vertical velocity by thrust modulation supplied, in the case of the X-14A, by the engine throttle is equally as important as the attitude control. Figure 8 presents a time history of the changes in thrust during portions of two of the trajectories; these are representative of all maneuvers made. The variation of thrust with time indicates that the changes were small and approximated step inputs. The magnitude of

these inputs appeared to be approximately a 0.05 thrust-to-weight-ratio increment. The type of throttle motions exercised during this investigation indicates that it might be feasible to use a step type of thrust control instead of proportional control.

Pilot's Observations of the Trajectories

Of the five trajectories investigated, the pilot preferred the straight-line approach of trajectory 1 for several reasons. First, the constant angle approach makes it easier to detect deviations from the desired conditions. Second, fewer power and attitude adjustments are required, so that the maximum number of variables is held constant. Third, rates are easier to judge and, since the declination of the line of sight to the landing area from the horizon is small, the flight path is easy to maintain.

Although none of the profiles imposed any stringent control requirements, with the vertical descent (No. 3), the landing spot was not in sight; and above 100 feet, rate of descent was very difficult to judge, requiring the sink rate to be monitored on the rate-of-climb indicator. With fewer landmarks and with unfamiliar terrain this effect will be even more pronounced. The steep aproach indicated in trajectory 2 had no direct advantage over the straight approach (No. 1) and, except for the visibility requirements, it was performed as easily. Trajectory 4, investigated to determine the effects of a reduced flight-path angle during the last portion of the approach, offers the advantage of reduced time as a consequence of higher forward speed which the pilot will accept at low sink rates. Thus, he will use higher average speeds for the mission without becoming oversensitive to control. The airplane type controls (stick, rudder pedals, and throttle) used during these tests did not affect the pilot's evaluation of the task being performed.

In the earth gravitational field, where the pilot has been trained to judge the acceptability of sink rates by his ability to arrest them, a sink rate of 10 feet per second will be used for a VTOL aircraft as long as a rate of change of about 3 feet per second squared is available. If this same response is to be obtained on the moon, 60 percent more thrust than is required for hover will be required for height control while on the earth only a 10-percent change is required. This imposes a more stringent requirement for the response of the thrust producer. On the earth a 10-percent change in thrust with a maximum of 0.2 to 0.3 second time constant has been previously found desirable, while the moon operation will require a 60-percent change in the same amount of time.

In using the X-14A to simulate a lunar landing it is recognized that differences in gravitational fields will require differences in attitude for a given translational acceleration. Because the thrust required for hover near the moon is one-sixth of that near the earth, to achieve a given horizontal acceleration of a given mass, the thrust vector must be tilted approximately six times farther near the moon than near the earth. During the acceleration from the initial condition to descent along the flight path and deceleration to a hover, the maximum change in pitch altitude was about 3°. To extrapolate to the

lunar gravity case this attitude change of six times would result in a change of 18° to 20°. During other evaluations on the jet supported airplane, pitch attitude changes of this magnitude have been evaluated and found to be controllable and acceptable from the pilot's standpoint.

To follow a precise trajectory with only visual references it is necessary that the pilot be able to see both the landing site and the horizon. The landing site is observed in order to control flight path, and the horizon is used as an attitude reference. The angle between the line of sight to the target and the horizon is used to detect changes in flight-path angle and to monitor and determine rate of descent. The steeper the flight-path angle with respect to the horizon, the greater the pilot's visual field will have to be. To perform a vertical descent quickly and precisely, portions of the field of view over a range of 90° in the vertical plane would appear to be necessary. With the visibility of the horizon and the touchdown point supplied to the pilot the lunar landing trajectory can be performed satisfactorily.

CONCLUDING REMARKS

A flight investigation of several problems associated with the visual landing on the lunar surface, using the X-14A VTOL test vehicle, indicated the following:

The pilot could perform all trajectories investigated without difficulty. The straight-line profile from initial point to prescribed landing point appeared best to the pilot although not the most economic from the fuel standpoint.

Since the profile was tested in the earth gravitational field, attitude changes were small, in the order of 3°, and predominantly about the pitch axis.

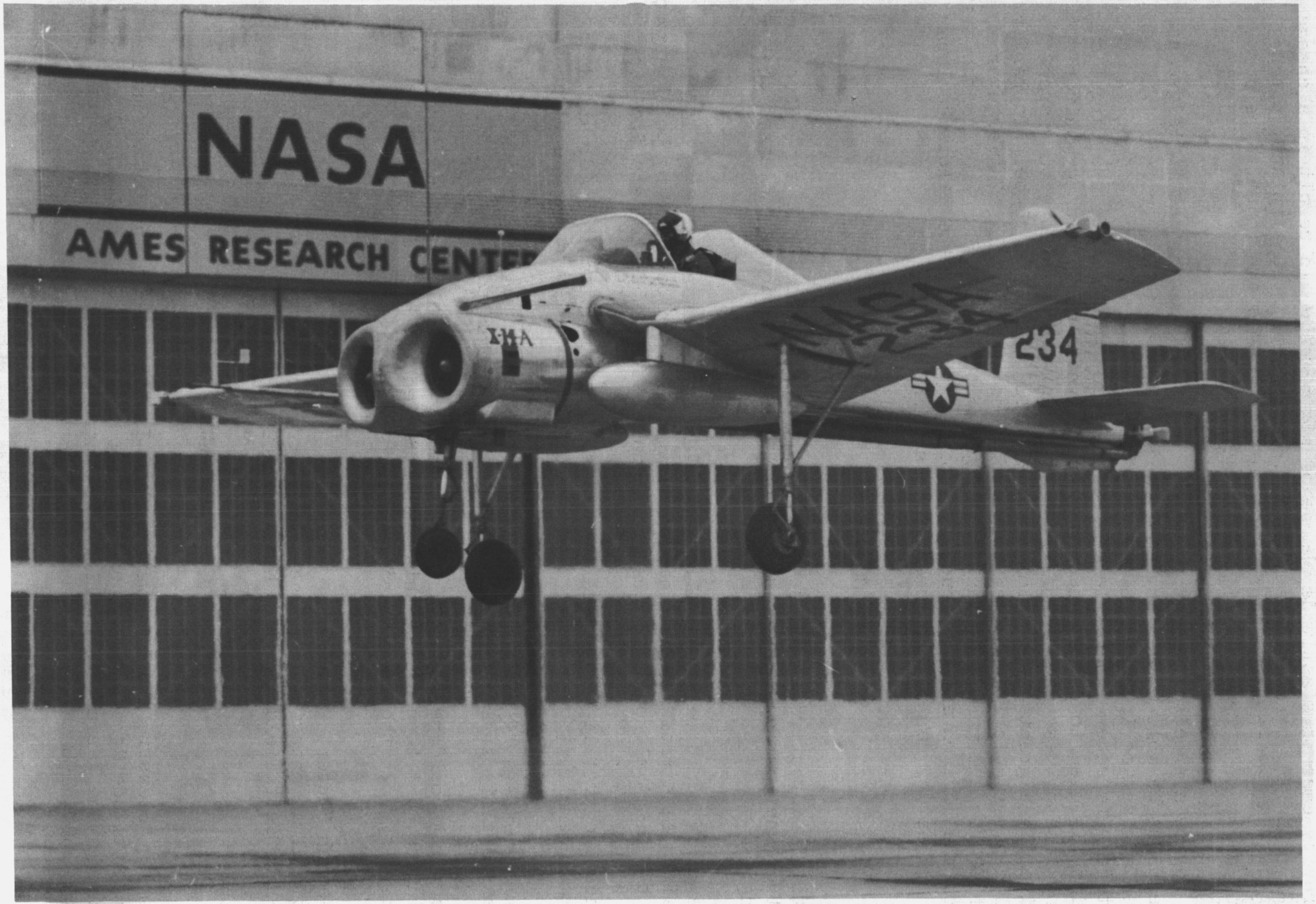
Only 20 percent of the control power required for a hovering VTOL vehicle in the earth's atmosphere was used during these simulated lunar landings.

The pilot could perform the mission easily with only outside visual and motion inputs, and to complete this task efficiently, he desires a field of view including both the prescribed touchdown point and the horizon.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Nov. 6, 1962

REFERENCE

1. Rolls, L. Stewart, and Drinkwater, Fred J., III: A Flight Determination of the Attitude Control Power and Damping Requirements for a Visual Hovering Task in the Variable Stability and Control X-14A Research Vehicle. NASA TN D-1328, 1962.

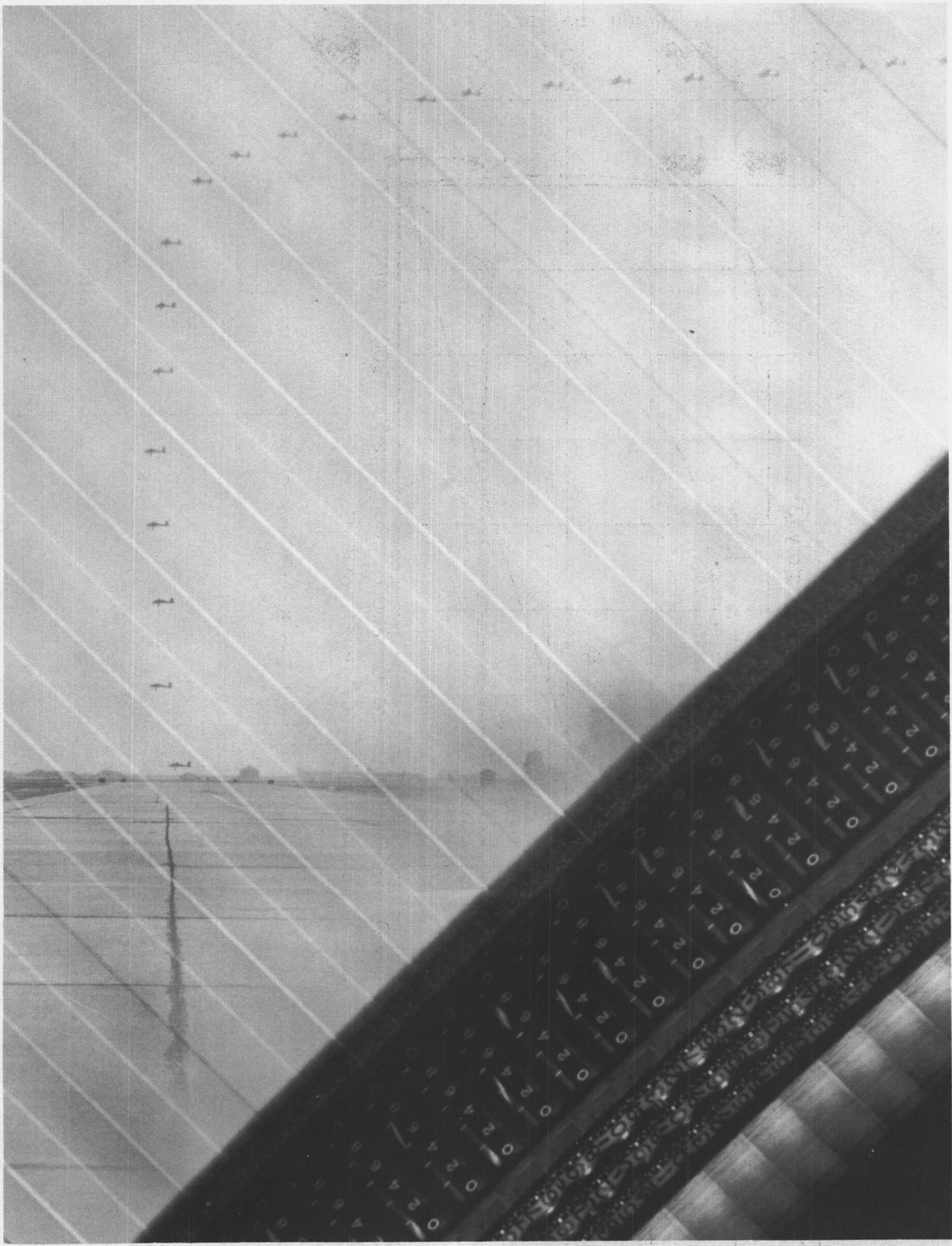


A-28473-8

Figure 1.- Photograph of the test vehicle (X-14A) in hovering flight.

Figure 2.- Pilot's view of landing area from the start of trajectory.

A-29688-6.1



A-29688

Figure 3.- Photograph of a portion of profile number 3.

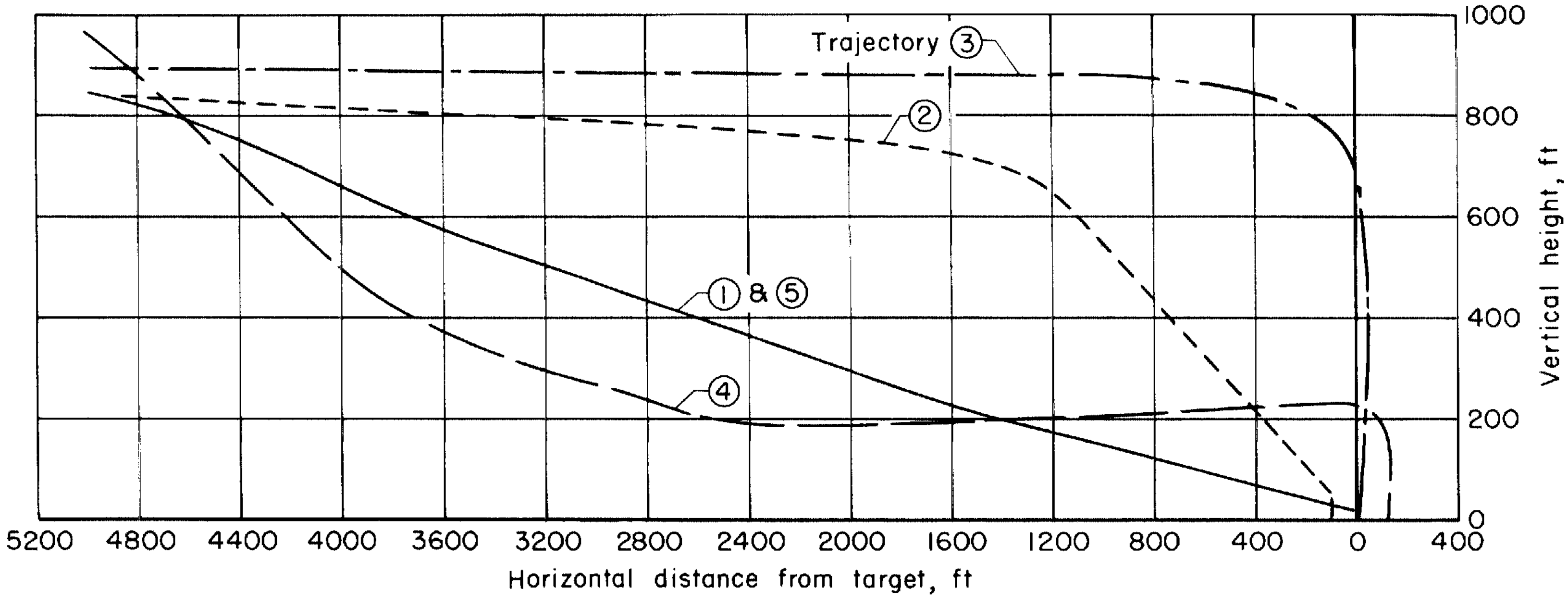


Figure 4.- Flight paths investigated.

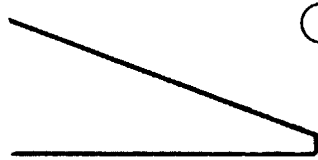
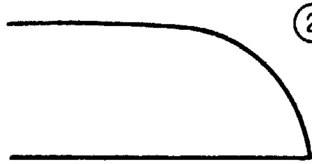
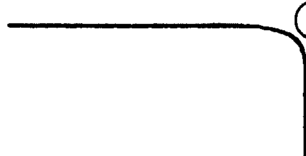
TRAJECTORIES	TIME SEC	STANDARD DEVIATION OF CONTROL MOTION PERCENT OF TOTAL NOZZLE DEFLECTION - ONE SIDE	
		PILOT	DAMPING AUGMENTOR
1 	105	12.2	2.5
2 	102	15.3	2.1
3 	120	15.4	2.3
4 	91	20.5	2.9
5 	113	13.8	0

Figure 5.- Comparison of the time and control inputs required to complete the various trajectories.

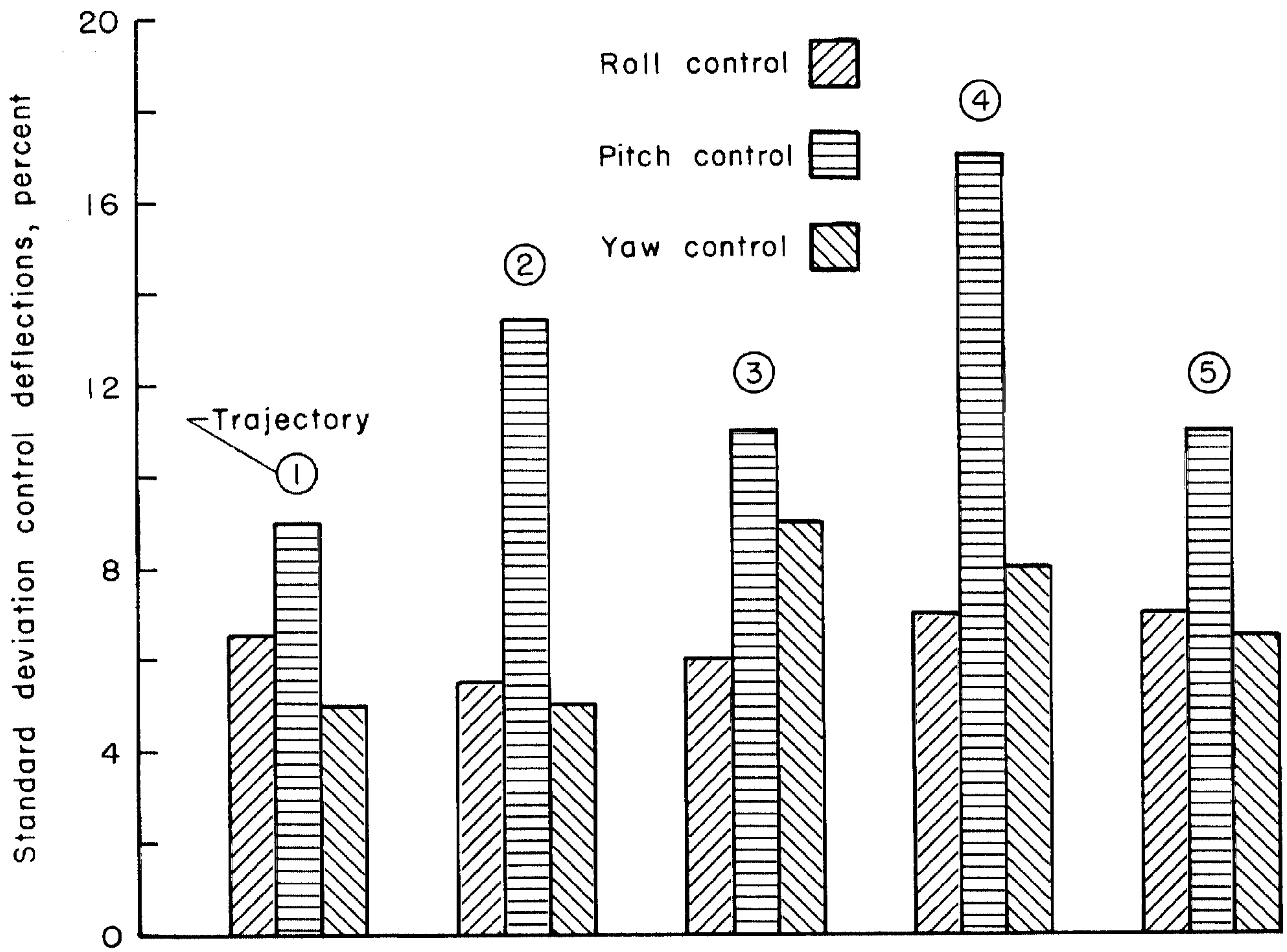


Figure 6.- Standard deviation of control motions during the various trajectories.

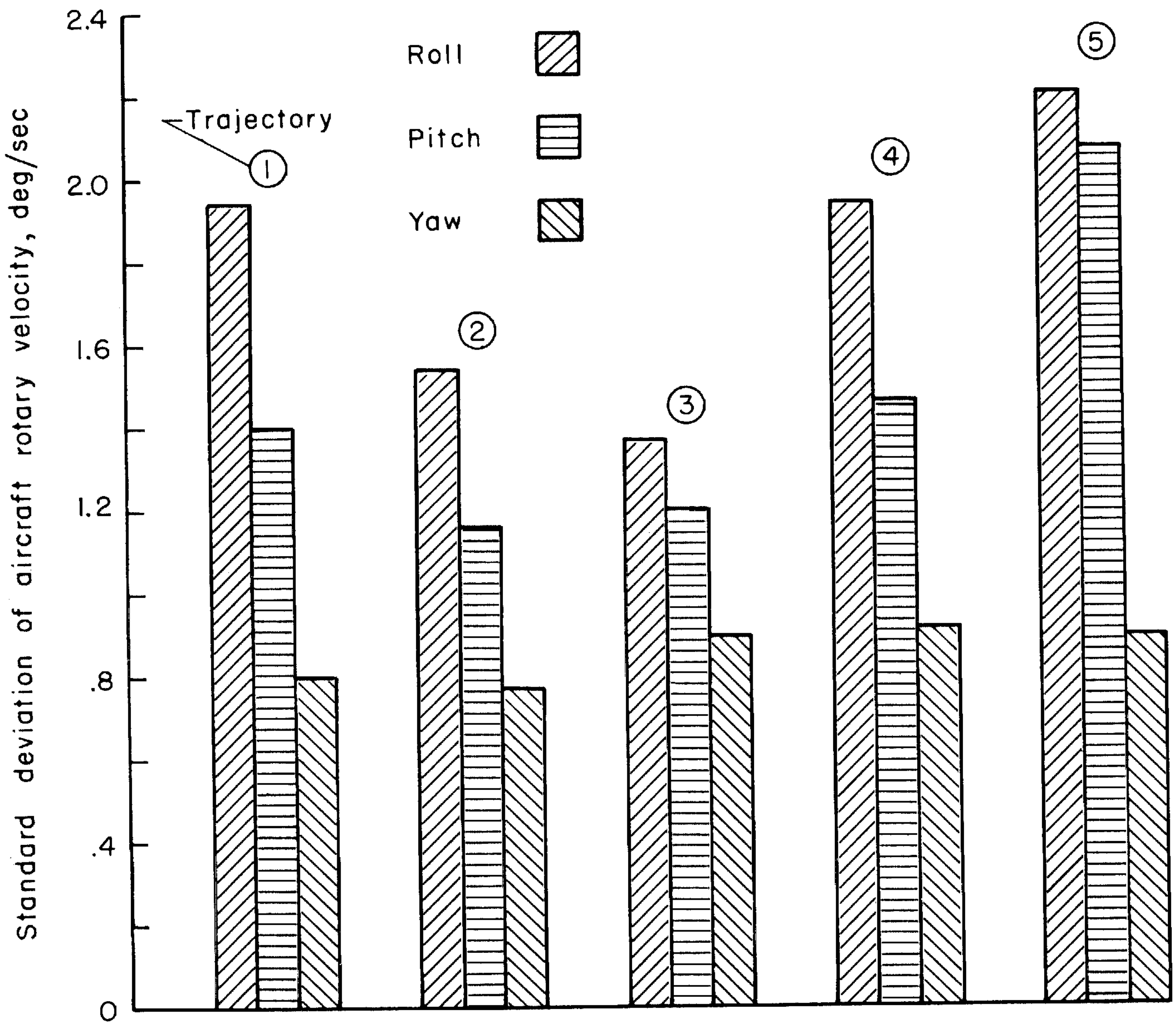
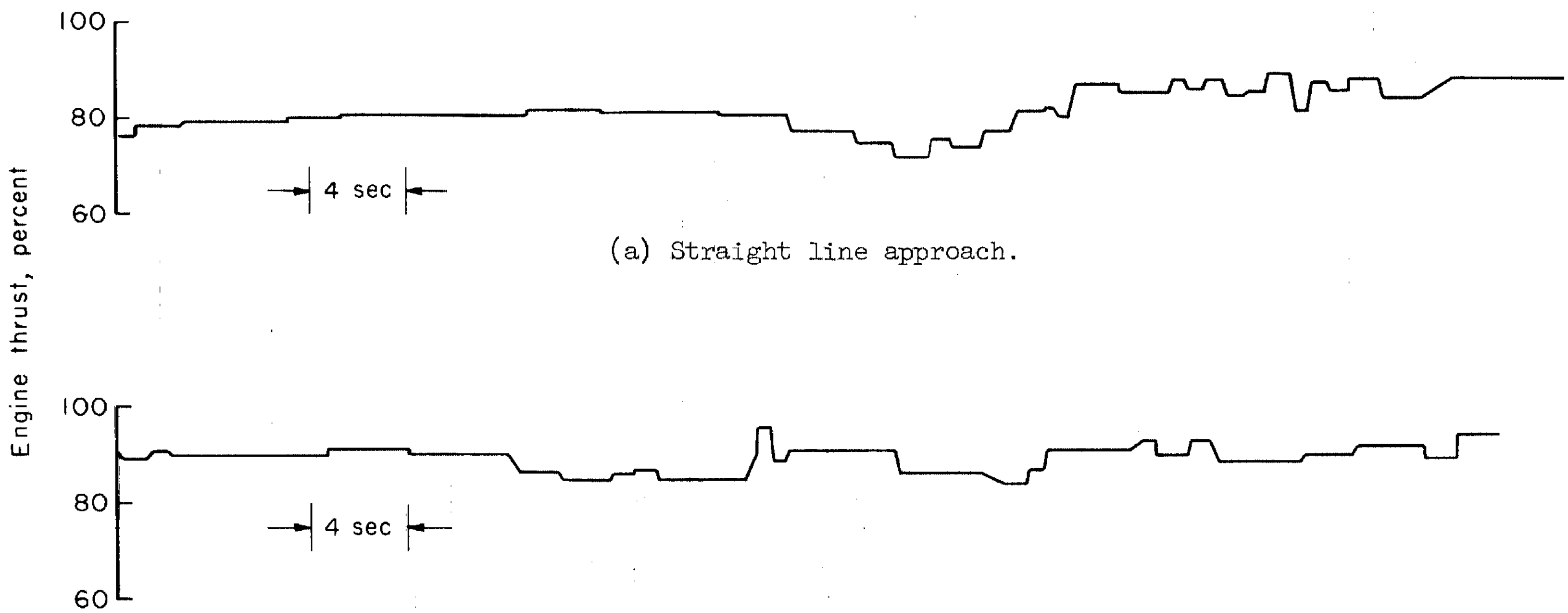


Figure 7.- Standard deviation of aircraft motion during the various trajectories.



(a) Straight line approach.

(b) Vertical descent approach.

Figure 8.- Time history of thrust changes during a portion of the trajectory.

NASA-Langley, 1963 A-725